PRACTICAL PHYSICS

A. H. Worthington

English School-Classics

EDITED BY FRANCIS STORR, M.A.,

CHIEF MASTER OF MODERN SUBJECTS IN MERCHANT TAYLORS' SCHOOL.

Small 8vo.

THOMSON'S SEASONS: Winter.
With an Introduction to the Series. By the Rev. J. F. BRIGHT. *1s.*

COWPER'S TASK. By FRANCIS STORR, M.A. *2s.*
Part I. (Book I.—The Sofa; Book II.—The Timepiece) *9d.* Part II. (Book III.—The Garden; Book IV.—The Winter Evening) *9d.* Part III. (Book V.—The Winter Morning Walk; Book VI.—The Winter Walk at Noon) *9d.*

SCOTT'S LAY OF THE LAST MINSTREL.
By J. SURTEES PHILLPOTTS, M.A., Head-Master of Bedford Grammar School. *2s. 6d.*; or in Four Parts, *9d.* each.

SCOTT'S LADY OF THE LAKE.
By R. W. TAYLOR, M.A., Head-Master of Kelly College, Tavistock. *2s.*; or in Three Parts, *9d.* each.

NOTES TO SCOTT'S WAVERLEY.
By H. W. EVE, M.A. *1s.*; WAVERLEY AND NOTES, *2s. 6d.*

TWENTY OF BACON'S ESSAYS. By FRANCIS STORR, M.A. *1s.*

SIMPLE POEMS.
By W. E. MULLINS, M.A., Assistant-Master at Marlborough College. *8d.*

SELECTIONS FROM WORDSWORTH'S POEMS.
By H. H. TURNER, B.A., late Scholar of Trinity College, Cambridge. *1s.*

WORDSWORTH'S EXCURSION: The Wanderer.
By H. H. TURNER, B.A. *1s.*

MILTON'S PARADISE LOST. By FRANCIS STORR, M.A.
Book I. *9d.* Book II. *9d.*

MILTON'S L'ALLEGRO, IL PENSEROSO, AND LYCIDAS.
By EDWARD STORR, M.A., late Scholar of New College, Oxford. *1s.*

SELECTIONS FROM THE SPECTATOR.
By OSMUND AIRY, M.A., late Assistant-Master at Wellington College. *1s.*

BROWNE'S RELIGIO MEDICI.
By W. P. SMITH, M.A., Assistant-Master at Winchester College. *1s.*

GOLDSMITH'S TRAVELLER AND DESERTED VILLAGE.
By C. SANKEY, M.A., Assistant-Master at Marlborough College. *1s.*

EXTRACTS from GOLDSMITH'S VICAR OF WAKEFIELD.
By C. SANKEY, M.A. *1s.*

POEMS SELECTED from the WORKS OF ROBERT BURNS.
By A. M. BELL, M.A., Balliol College, Oxford. *2s.*

MACAULAY'S ESSAYS:
MOORE'S LIFE OF BYRON. By FRANCIS STORR, M.A. *9d.*
BOSWELL'S LIFE OF JOHNSON. By FRANCIS STORR, M.A. *9d.*
HALLAM'S CONSTITUTIONAL HISTORY. By H. F. BOYD, late Scholar of Brasenose College, Oxford. *1s.*

SOUTHEY'S LIFE OF NELSON. *2s. 6d.*
By W. E. MULLINS, M.A.

GRAY'S POEMS with JOHNSON'S LIFE AND SELECTIONS from GRAY'S LETTERS. By FRANCIS STORR, M.A. *1s.*

Rivingtons: London, Oxford, and Cambridge.

[c—449]

Rivington's Mathematical Series

Small 8vo.

By J. HAMBLIN SMITH, M.A.,

OF GONVILLE AND CAIUS COLLEGE, AND LATE LECTURER AT ST. PETER'S COLLEGE, CAMBRIDGE.

Algebra. Part I. 3*s.* Without Answers, 2*s.* 6*d.* A KEY, 9*s.*

Exercises on Algebra. Part I. 2*s.* 6*d.*

[Copies may be had without the Answers.]

Elementary Trigonometry. 4*s.* 6*d.* A KEY, 7*s.* 6*d.*

Elements of Geometry.

Containing Books 1 to 6, and portions of Books 11 and 12 of EUCLID, with Exercises and Notes. 3*s.* 6*d.* A KEY, 8*s.* 6*d.*

PART I., containing Books 1 and 2 of EUCLID, may be had separately. *Limp cloth*, 1*s.* 6*d.*

Elementary Hydrostatics. 3*s.* } A KEY, 6*s.*

Elementary Statics. 3*s.* }

Arithmetic. 3*s.* 6*d.* A KEY, 9*s.*

Book of Enunciations

FOR HAMBLIN SMITH'S GEOMETRY, ALGEBRA, TRIGONOMETRY, STATICS, AND HYDROSTATICS. 1*s.*

Elementary Heat. 3*s.*

By E. J. GROSS, M.A.,

FELLOW OF GONVILLE AND CAIUS COLLEGE, CAMBRIDGE, AND SECRETARY TO THE OXFORD AND CAMBRIDGE SCHOOLS EXAMINATION BOARD.

Crown 8vo.

Algebra. Part II. 8*s.* 6*d.*

Kinematics and Kinetics. 5*s.* 6*d.*

By G. RICHARDSON, M.A.,

ASSISTANT-MASTER AT WINCHESTER COLLEGE, AND LATE FELLOW OF ST. JOHN'S COLLEGE, CAMBRIDGE.

Crown 8vo.

Geometrical Conic Sections. 4*s.* 6*d.*

AN ELEMENTARY COURSE

OF

PRACTICAL PHYSICS

BY

A. M. WORTHINGTON, M.A., F.R.A.S.

ASSISTANT MASTER AT CLIFTON COLLEGE.

RIVINGTONS

WATERLOO PLACE, LONDON

Oxford and Cambridge

MDCCCLXXXI

[c—158]

CONTENTS.

	PAGE
Introduction,	1
The Laboratory,	5
List of Apparatus,	7
Rules,	11
The Course,	13
Measurement of Tables,	13
Measurement of Sphere,	14
Measurement of Cylinder,	14
Centre of gravity of cardboard,	15
Centre of gravity of triangle,	15
Centre of gravity of quadrilateral,	16
Centre of gravity of retort stand,	17
Testing accuracy of balance,	17
Making of weights for balance,	18
Measurement of length of wires,	18
Measurement of areas,	19
Cubical contents of test tube,	21
Density of liquids,	21
Density of metal cylinders,	22
Elasticity,	22
Elasticity of india-rubber,	22
Influence of length on stretching,	22
Limits of simple elasticity for india-rubber,	23
Influence of cross section of cord,	24
Co-efficient of elasticity,	25
Torsion,	25
Influence of thickness on torsion,	27
Influence of material,	27
Surface tension of liquids,	27
Difficulty of breaking through surface,	28

PAGE

Simple pendulum, ... 28
To prove the law of the simple pendulum, ... 28
Hydrostatics, ... 30
Specific gravity pan, ... 30
Principle of Archimedes, ... 30
Density of metal by displacement, ... 30
Density of penny, and calculation of composition, ... 31
Density of boxwood ball, ... 31
To find average thickness of a wire, ... 32
Density of liquids by method of balancing columns, ... 32
Density of liquids by weighing in the liquid, ... 33
Density of liquids by hydrometer, ... 33
Density of boxwood by flotation of cube, ... 33
Density of boxwood by flotation of prism, ... 34
Density of solid in small pieces, ... 35
Density of Sodium, ... 35
Torricelli's Experiment, ... 36
Boyle's law for pressures greater than an atmosphere, ... 36
Boyle's law for pressures less than an atmosphere, ... 38
Heat, ... 40
Verification of thermometer readings, ... 40
Definition of the unit of heat, ... 40
Unit of heat nearly constant, ... 40
Observation of cooling, ... 41
Specific capacity of Calorimeter, ... 42
Specific capacity of Thermometer, ... 43
Specific heat of a metal, ... 44
Latent heat of water, ... 46
Latent heat of steam, ... 46
Co-efficient of expansion of air : first method. Constant volume, 49
Co-efficient of expansion of air : second method. Constant pressure, 50
Co-efficient of apparent expansion of mercury in glass, ... 51

INTRODUCTION.

AMONG a series of questions lately circulated amongst the scientific masters of the larger public schools by a Committee of the Head Masters' Conference, and which, with the answers to them, were published as an Appendix to their Report for 1877, was the following:—

"Suggestions as to how far Physical Laboratory work is possible at School, having regard to the time at a boy's disposal."

Out of eighteen answers, only two are favourable; the following from Rugby warmly so:—

"Most desirable that Physical Laboratory work should be done in all schools where Physical Science is taught—1*st,* Because manipulation and observation is an important education in itself; 2*d,* Because it is necessary to elevate Science from a mere cram subject."

The spirit of the other answers seems well represented in the following, from the Royal Naval College:—

"I do not think Physical Laboratory work of much educational value, unless accompanied by measurements. Experiments merely qualitative only lead to play. Measurements can be made only by costly instruments. I should be inclined to discontinue Physical Laboratory work in schools, except in the case of senior boys. A master cannot take more than seven or eight boys at a time. Each experiment would average two hours. Single hours now and then useless."

It seems indeed generally admitted that practical work in Physics is very desirable, but the difficulties are thought to be insurmountable. Accordingly the stress is laid on practical work in Chemistry, not because it is a better subject from an educational point of view, but because such is thought to be the only course available.

Yet it will hardly be denied by any scientific man, that from an educational point of view the first place should be accorded to the study of Physics. Logically it precedes all the other experimental sciences, every one of which has its own special instruments and mechanical appliances, whose action is purely physical, and the ability of the scientific man to advance our knowledge in any direction depends very largely on the readiness with which he understands, handles, and devises such appliances. And yet this fundamental study, which should beyond all others be sound and thorough, is in danger of being left in the condition of "a mere cram subject."

The reason is to be sought in the fact, that nearly all who have tried practical work in Physics with junior boys have aimed too high. They have seen no alternative between "merely qualitative work only leading to play," and "measurements by costly instruments requiring on an average two hours for each experiment." For the elementary course which follows no costly apparatus is required, but exact measures are demanded, within the limits of the apparatus.

The course was originally devised for a class of twelve boys, whose average age was rather under fourteen, and was in use for some time at the Salt Schools, where the time taken for it was a school year of two separate hours a week. The result was very encouraging, and the same course is about to be used for a class of thirty boys at Clifton College.

The author claims for such a course that it affords a good training in—(1) skilful manipulation; (2) exact observation; (3) intelligent and orderly recording of observations; (4) principles of indirect measurement; (5) the application and intelligent use of Arithmetic, Geometry, and easy Algebra; (6) the varying of experimental combinations; (7) *common sense;* and he is convinced that for most boys the intellectual value of such work is much greater than that of the usual school course of chemical analysis, which, after the method has once been mastered, appeals too exclusively to the memory.

An additional claim for such an elementary course is, that more exact work with costlier instruments later on is thereby rendered much more feasible. Even at the Universities, it is the want of elementary experience and acquaintance with common instruments on the part of the students in the physical laboratories that makes progress slow, and a long preliminary training necessary.

The course, as now published, has stood the test of experience at Saltaire with a class of twelve boys. It is obviously capable of much extension; but in such a matter experience is everything, and the author is unwilling to make any additions which have not been submitted to its test.

The connection between the course and the experimental lectures, which the boys also attended, was important; the instructions which follow the experiments are meant to contain, in a clear, summarised form, the information which the boys have already received from lectures.

In order to avoid loss of time in starting at a fresh experiment, it is necessary that these instructions should be very complete, and constant reference to them should be insisted on.

Every boy is supposed to be able to do simple equations, and to have read at least two books of Euclid before reaching the middle of the course.[1] The boys worked in pairs,—a method found on the whole to be satisfactory. Each pair worked quite independently of the rest, some getting on a good deal faster than others. This is an advantage, not only because it renders it unnecessary to keep apparatus enough for all to be doing the same thing at once, but also because it makes each boy feel that his progress is in his own hands, and he is much more inclined to think for himself under such circumstances.

The precise order of the experiments is not always material, and some discrimination should be used, so that a dull boy shall not be set to do anything of which the mathematics are beyond his powers.

Experiments marked ‡ were often omitted in the case of poor mathematicians.

Experience has shown that some of the easiest parts of the course are most valuable. Especially useful are Experiments 12 and 13, which are taken from Professor Hinrich's *Elements of Physics*, which contains many useful suggestions. As regards the precision attainable with the apparatus recommended, it may be mentioned that the errors of results have been—

In the case of	densities of solids,	about	1	per cent.
„	„ liquids,	„	$\frac{1}{2}$	„
„	specific heats,	„	5 to 10	„
„	verification of Boyle's law,	„	$\frac{1}{4}$	„

All mention of small corrections for temperature and pressure has been purposely avoided, as introducing complicated formulæ and obscuring the main issues; but the

[1] A lecture once a week on easy physical problems in mathematics, *very varied in kind*, was found extremely useful.

more intelligent boys find out for themselves the need of such corrections, and the direction of their effect on the result.

THE LABORATORY.

The chief essentials are light, table space, and some blank wall, in front of which pendulums, wires, elastic cords, etc., can be hung.

The laboratory of the Salt Schools was made out of an originally open shed. Each pair of boys had half of a strong firm table, about 3 feet 2 in. high,[1] 4 feet wide, and 3 deep, placed against the wall under a window. This space was rather too small, not, indeed, for the experiments alone, but for the convenient use of note-books as well; but it is advantageous to work at a corner of a table, so as to be able to get at the apparatus from two sides. The tables were provided with pear-headed gas-taps for use, with Bunsen's burners, and close to each table was a water-tap and small sink. This arrangement of the water is not absolutely necessary for physical work, and was introduced for convenience in chemical experiments, for which the room was often used, slabs outside the windows being useful in place of stink-cupboards. In one corner of the room was a water-tap and slopstone, which is very necessary.

In a room in which water was not laid on, a small cistern or water-butt would be quite sufficient; and in the absence of gas, spirit-lamps would, I should think, do perfectly well; but I have no experience of them.

A useful addition to the fixtures would be a large gas flame, with a kettle to supply hot water, and so save much of the time taken up in raising water to the boiling

[1] 2 ft. 10 in. is a better height.

point. This should be placed as far as possible from the experimenting tables.

Underneath the tables were cupboards, in which part of the apparatus was permanently kept, being in constant use. The rest of the larger apparatus was kept in easily accessible cupboards or on shelves, while for the smaller a watchmaker's cabinet was found very convenient. The table-tops should be cut quite square at the edge, without any bevel, and should project 3 or 4 inches beyond any cupboard or woodwork below.

In my own tables a vertical hole was bored near each of the outside corners to receive an upright staff, with a small arm at right angles to it for hanging the balance, which was part of the permanent apparatus of the table.

Against the blank wall were fixed, along the whole length of the room, two thick horizontal wooden beams, at heights of about 7 and 10 feet from the floor, into which, at intervals of every two or three feet, were bored holes to admit the stalks of the clamps (mentioned in the List of Apparatus No. 1), for holding wires, pendulums, and india-rubber cords for experiments on elasticity.

Breakages, from the nature of the apparatus, were rare, and were always paid for by the breaker. About 15s. covered a year's breakages for the whole class. It was thus unnecessary to charge any laboratory fee.

The following is a list of the apparatus used, with price.[1] The quantity given has been found enough for twelve boys:—

1. Apparatus required by each pair of boys, and best kept in cupboards under or near the work-tables:—

Balance,[2]	£0	4	0
Set of gramme weights, from ·01 to 1000 grammes, ...	0	3	6
*Metre measure, divided to millimetres,[3] .	0	1	6
*Half-metre, ditto.,[3] . .	0	0	9
Small test-tube stand, ...	0	1	3
Six test-tubes, assorted up to 1 in. in diam.,	0	0	6
Retort-stand, with rings, two clamps, and wire gauze, ...	0	10	6
Six watch-glasses, ...	0	0	6
Bunsen's burner, ...	0	1	6
Test-tube clip, ...	0	1	3
Two feet caoutchouc gas-tubing, . .	0	0	8
Wide 4 oz. beaker, ...	0	1	3
*Upright staff, with arm at right angles, 1 ft. high, for holding balance, . .	0	0	4
Total, . .	£1	7	6

[1] The price, unless otherwise stated, is that at which Messrs. Mottershead and Co., 7 Exchange Street, Manchester, have kindly undertaken to supply the apparatus.

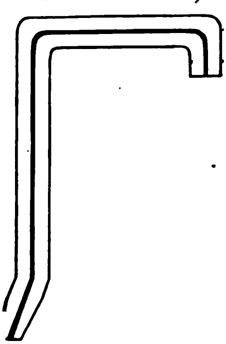
Those things to which an asterisk is attached are not usually kept in stock by instrument makers, but may be obtained without difficulty elsewhere at the price mentioned.

[2] Of several cheap balances tried, the most suitable was the Australian gold scales, 8 in. beam, No. 135 B in the Catalogue of Messrs. Day and Millward, Suffolk Street, Birmingham.

[3] Supplied by Messrs. Rabone and Sons, Hockley, Birmingham.

2. The following should be kept in common stock :—

One set of accurate gramme weights, 50 gr. to ·001 gr., ...	£1	15	0
Six child's stone marbles, about 1″ in diam.,	0	0	3
Two pairs of callipers, ...	0	2	0
*Four pounds of sheet lead, . . .	0	1	0
Three pairs of large scissors, . . .	0	6	0
*Two sq. feet of sheet brass, about $\frac{1}{50}$″ thick, .	0	1	4
*Two sheets of thick cardboard, . . .	0	1	4
* „ „ thin „ . .	0	0	8
*Steel, brass, iron, and copper wire. In each metal 40 feet of each of the following sizes :—B.W.G. 20, 23, 30, . .	0	5	0
*20 feet brass wire, size 12, . . .	0	0	7
Glass tubing, from $\frac{1}{8}$ to $\frac{3}{4}$ in. internal diam., about 5 lbs., ...	0	6	8
Three glass files, ...	0	2	0
Six feet india-rubber gas tubing, . .	0	2	0
„ „ small tubing for junctions of glass-tubes, ...	0	1	6
*Paraffine candles, ...	0	1	0
*Metal cylinders, accurately turned, about $1\frac{1}{2}$″ long $\frac{5}{8}$″ in diam., three of iron, three of copper, three of brass, ...	0	3	0
Three 50 gramme spec. grav. bottles, two with mark on neck, one with perforated stopper,	0	4	6
Two additional stoppers for same, shaped thus, made of capillary tubing, so that the whole can be used as a weight thermometer, . . .	0	3	0
Carry forward, .	£3	16	10



	£	s.	d.
Brought forward, . .	£3	16	10
Six hydrometers, three for light and three for heavy liquids, and three trial jars, . .	0	16	3
Four dozen assorted corks, ...	0	1	4
Three pieces of india-rubber cord, $\frac{1}{8}''$ thick, 8 ft. long. „ „ $\frac{1}{4}$ „ „ „ $\frac{1}{2}$ „	1	12	0
*Half-a-pound of iron tacks for spec. heat, .	0	0	6
„ copper clippings, „ .	0	0	9
Six centigrade thermometers, ...	0	12	0
Four barometer tubes, ...	0	6	0
Two narrow glass tubes, $\frac{3}{16}''$ internal diam., 6 feet long, with 1 foot closed and turned up, to form manometer, ...	0	3	0
Two wooden upright stands for same, each consisting of a board about 5 in. wide and 5 ft. high, on firm foot, to which the tube can be clipped by an india-rubber ring, .	0	6	0
*Six cylindrical vessels of *very* thin sheet brass, 3″ high $1\frac{1}{2}''$ wide, as calorimeters, .	0	2	0
Six tinned outer vessels, 3″ high 2″ wide, .	0	1	6
*One pair of metal clippers, ...	0	2	6
*One pair of pliers, ...	0	1	6
Eight lbs. of mercury (varies, say at 3/ per lb.),	1	4	0
Set of cork-borers, ...	0	2	0
Three large beakers, 8″ high, ...	0	3	6
Three boxwood balls, about 1″ in diam., .	0	1	6
Turpentine, 1 quart (with bottle), . . .	0	2	4
Methylated spirits, 1 quart, „ . . .	0	2	9
Naphtha, 1 quart, „ . . .	0	2	8
Three small mortars, to hold mercury for barometer experiments, ...	0	2	6
Carry forward, . .	£10	3	5

Brought forward, . .	£10	3	5
*Three trays for mercury experiments, . .	0	2	6
Two cubes of boxwood, 2″ in the side, .	0	2	0
Two right triangular prisms of boxwood, 3″×2″×2″, ...	0	2	0
Three glass funnels of 1″ and three of 2″ diam., ...	0	0	9
Sodium, ...	0	1	0
Six 4 oz. and six 6 oz. flasks, . . .	0	4	6
Six 2 oz. and six 4 oz. test-glasses, . .	0	2	6
Total, . .	£10	18	8

ADDITIONAL.

Pins. Thread. String.

A set of rectangular blocks of seasoned deal, each about 5 in. square, and varying in thickness from 1 in. to ¼ in.

For verifying the "Principle of Archimedes," little paper cases, into which the metal cylinders would exactly fit, were made by rolling a strip of pasted writing-paper round one of the cylinders, so as to form a strong tube, which, when dry, was cut into lengths rather longer than the cylinder. The ends of these were then closed by sticking them vertically to the depth of about ¼ in. in soft plaster of Paris, which, on hardening, made a tight plug. The whole was then rendered waterproof by dipping in melted paraffine, and finally trimmed down, so that the internal depth was exactly that of a cylinder.

The master should also prepare the wires, and metal or cardboard figures used in experiments 12 and 13.

Rules to be observed by Boys working in the Laboratory.

1. Read all about the experiment, so as to have a clear idea of what you are going to do before you begin.

2. Remove all apparatus from the table to its proper place *as soon as it is done with.*

3. The form in which the experiment is to be recorded should be got ready beforehand, so that as soon as an observation is made it can be recorded in its right place in the form.

4. The numbers thus recorded in pencil in the rough note-book must not be the result of additions or subtractions done in the head, but the numbers on which such calculations, however short, depend.

5. When the measure made by the second observer of a pair differs from that made by the first, both must be recorded, and the mean of the two must be taken.

6. Make all the necessary observations before proceeding to any calculation.

7. No record is to be copied into the fair note-book till passed by the master.

8. All breakages to be reported at once to the master, and put down in the breakage-book.

AN ELEMENTARY COURSE OF PRACTICAL PHYSICS.

EXPERIMENT 1.—*Measure the size and height of the top of your working table, and record the measures.*

Instructions.—Measure the length, breadth, thickness, and height at each corner and at the middle of each side, recording each measure as follows, and then taking the mean or average.

Measures of Length.	Measures of Breadth.	Measures of Thickness.	Measures of Height.
.... cm.	.... cm.	.... cm.	.... cm.
....	....	....	....
....	....	....	....
....	....	....	....
Mean length = ...	Mean breadth = ...	Mean thickness = ...	Mean height = ...

N.B.—Record all measures of length in centimetres or decimal parts of a centimetre.

EXPERIMENT 2.—*Measure the diameter of the sphere given you by placing it between two rectangular blocks.*

Instructions.—Choose two blocks rather thicker than the semi-diameter of the ball.

To get their faces parallel, place their ends against the face of a third block as in the figure.

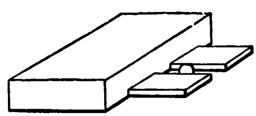


FIG. 1.

EXPERIMENT 3.—*Measure the diameter of the same sphere by placing it between two measures.*

Instructions.—First place the ends of the two metre measures against the perpendicular face of a block, as in the figure, supporting them on their edges by means of other blocks if necessary, and just so far apart as to admit of the ball passing between them.

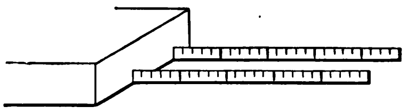


FIG. 2.

Place the ball between them, touching the block, and, using one eye only, move the head until the vertical part of the circumference of the ball appears to be in the line of sight with two corresponding divisions of the measures.

EXPERIMENT 4.—*Verify by measuring the circumference of the ball with a strip of paper.*

Instructions.—The circumference of any circle is 3·14159 . . . times its diameter.[1] For general purposes it is sufficiently exact to take this number as 3·1416, or, still more roughly, as $3\frac{1}{7}$ (=3·1428). It is found convenient to express the ratio between the circumference of a circle and its diameter by the Greek letter π. Thus we say that the circumference of a circle is π times its diameter, or

$$\text{circumference} = \text{diam.} \times \pi,$$

instead of

$$\text{circumference} = \text{diam.} \times 3{\cdot}14159 \ldots$$

EXPERIMENT 5.—*Measure the dimensions of the iron cylinder given you, and thence calculate the weight of it, supposing* 1 *cubic centimetre of iron to weigh* 7·5 *grammes.*

[1] **How would you test this statement experimentally?**

Instructions.—The area of a circle is π times the radius squared. Thus if r be the radius of a circle, its area is πr^2; and the volume of a cylinder is its length multiplied by the area of its base $= \pi r^2 l$.

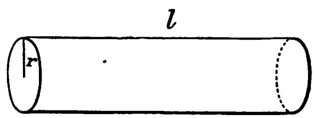


FIG. 3.

EXPERIMENT 6.—*Find the centre of gravity of the sheet of cardboard given you by the method of intersecting plumb-lines.*

Instructions.—Make a plumb-line by fastening a bit of lead to the end of a thread. Hang up the sheet loosely on a pin stuck through it anywhere into the edge of your table; hang the plumb-line over the pin, and observe where it intersects the edge of the cardboard. Draw with pencil a line on the cardboard from this point to the pin hole. Repeat the process, sticking the pin through the card in other places. The point where all the plumb-lines intersect gives the centre of gravity of the card. Verify by balancing on a pin-point.

EXPERIMENT 7.—*Find in the same way the centre of gravity of the cardboard triangle given you, and thence discover how to find the centre of gravity of any triangle by simple geometry.*

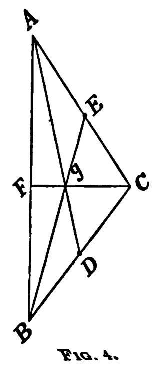


FIG. 4.

Instructions.—Letter the card triangle, ABC, call the centre of gravity found by the method of Experiment 6, or by balancing, G. Join AG, BG, CG by drawing lines on the card, and produce them to meet the opposite sides in D, E, and F. Now measure AF and FB; BD and DC; CE and EA; also, measure AG and GD; BG and GE; CG and GF. Record your measures in the following form, having first drawn in your

book a similar triangle with the same letters for reference :—

cm.	
$AF=$.........	$\therefore \frac{AF}{FB}=$.........
$FB=$.........	
$BD=$.........	$\therefore \frac{BD}{DC}=$.........
$DC=$.........	
$CE=$.........	$\therefore \frac{CE}{EA}=$.........
$EA=$.........	
	Mean,

cm.	
$AG=$.........	$\therefore \frac{AG}{GD}=$.........
$GD=$.........	
$BG=$.........	$\therefore \frac{BG}{GE}=$.........
$GE=$.........	
$CG=$.........	$\therefore \frac{CG}{GF}=$.........
$GF=$.........	
	Mean,

Now, on a fresh card triangle, of different shape, draw lines corresponding to AD, BE, and CF. Their intersection gives the centre of gravity. Test by balancing.

Express in your own words the law that you have now discovered for finding the centre of gravity of a triangle.

EXPERIMENT 8.—*Find by geometrical construction the centre of gravity of the rectilinear quadrilateral piece of card given you.*

Instructions.—Draw a diagonal, dividing the card into two triangles. Find geometrically, by the method of the last Experiment, the centre of gravity of each triangle; call these points M and N. Join M and N. Then if we consider all the matter in each triangle to be collected at its centre of gravity, we see that the whole may be regarded as a rod MN without weight, having a weight

equal to that of one triangle at M, and a weight equal to the other at N; ∴ the centre of gravity of the whole lies in MN at some point G, so situated that MG is to GN as the weight at N is to the weight at M. Measure, therefore, the area of each triangle (by multiplying the altitude into half the base). This gives the relative weights at M and N. Measure the line MN, and by arithmetic divide this length in the proportion of the areas of the two triangles. Now measure off the distance Mg or Ng thus obtained. g is the centre of gravity of the whole.

EXPERIMENT 9.—*Find the centre of gravity of your retort-stand.*

Instructions.—Hang it from a peg in the wall by a string tied, first near the bottom, and then near the top of the rod. Observe in each case where the plumb line from the point of suspension meets the base. Then draw to scale a section of the stand in your note-book, lettering it, and marking the points corresponding to those noted in the experiment, and draw lines corresponding to the positions of the plumb lines. Their intersection gives the position of the centre of gravity, which in this case is the point at which the whole would balance in any position, if connected with it by a rigid rod without weight.

The lengths of the lines measured on the real object for making the drawing, and the length on the reduced drawing, should be recorded separately from the drawing.

EXPERIMENT 10.—*Test the accuracy of the balance.*

Instructions.—In weighing, it is not necessary to wait till the balance is at rest to observe whether it is in equilibrium or not. If the pointer oscillates to equal distances at each side of the position of rest, it may be considered to be in equilibrium. With no weight in either pan the beam should be horizontal and the pointer vertical: a bit of paper or wire should be added to the lightest pan till

this is the case. Now place in the left-hand pan a 50 gram. weight, and counterpoise with shot and sand in a watch-glass in the other pan. Call this watch-glass No. 1. Remove the 50-gram. weight, and counterpoise with another watch-glass with shot and sand in place of the 50 grams. Call this watch-glass No. 2.

It is clear that even if the arms of the balance be of unequal length, the weight of the watch-glass No. 2 is exactly equal to 50 grams., since each serves to balance watch-glass No. 1.

Now, substitute the 50-gram. weight for watch-glass No. 1, and observe whether the balance is still in equilibrium. If not, one arm must be longer than the other. Add known weights (P) to the side that seems the lighter till equilibrium is restored.

Then

50 grams. in one pan balance $50+P$ grams. in the other;

$\therefore$ the arm on which the 50 grams. act is longer than that on which the $50+P$ grams. act, and the ratio between the lengths of the two is $\frac{50}{50+P}$.

So that the weights which are to counterbalance any object in weighing it are greater or smaller than the real weight (according as the object hangs from the long or the short arm) in the proportion $\frac{50}{50+P}$.

It is this ratio that you are required to find.

EXPERIMENT 11.—*Make for yourself, out of sheet-lead and copper wire, the weights necessary to complete your set.*

EXPERIMENT 12.—*You are given six straight wires and one twisted one, all cut from the same piece, and are required to find, by measuring and weighing the straight pieces, the average weight of a centimetre of the wire, and thence to calculate the length of the twisted piece.*

Instructions.—The observations are to be recorded in the following form :—

Finish all the weighing and measuring before doing any calculation.

No. of Wire.	*L.* Length in cm.	*W.* Observed wt. in grams.	$\frac{W}{L}$ Wt. of 1 cm.	*W'.* Calc. wt. of wire.	*E.* Error of $W-W'$.
No. 1.					
No. 2.					
No. 3.					
No. 4.					
No. 5.					
No. 6.					

Mean, ____________

	Weight.	Calc. Length.
Bent wire, . .	......	......

N.B.—The *calculated* weight W' of each wire is found by taking the *mean* value of the weight of 1 cm. as nearest the truth, and multiplying this by the length.

EXPERIMENT 13.—*You are given six rectangular figures cut out of the same sheet of brass or thick cardboard, and one piece that is curved at the edge. You are required, by measuring the area of each rectangular piece, and weighing it, to find the average weight of a square centimetre of the metal or card, and thence to find the area of the curved piece.*

Instructions.—When a piece is a polygon, it must be divided into triangles.

Record your observations in the following form, finishing the weighing and measuring before proceeding to calculation :—

No. of Piece.	Length of Base.	Altitude (if triangle).	Altitude (if parallelogram).	Area.	Weight.	Wt. of 1 sq. cm.	Calc. Wt.	Error.

Mean, ______ ______

Curved piece, Weight. [ ] Calc. Area. [ ]

NOTE.—How would you verify experimentally the formula, area of a circle of radius $r = \pi r^2$?

EXPERIMENT **14.**—*Find the cubical contents of a test-tube, by weighing the water that it contains.*

Instructions.—Remember that a cubic cm. of water weighs 1 gram., or that each gram. of water occupies 1 cubic cm.

To make a stand to hold the test-tube upright in the balance, bore a wide enough hole in a big cork. Make a file mark on the test-tube near the mouth, and fill it up to this mark, using at the last a short glass tube, which can be closed at one end by the finger.

EXPERIMENT **15.**—*Find the density, or specific gravity, of the liquids given you—*

(1.) *By using a test-tube.*
(2.) „ *specific gravity flask.*

Instructions.—The density of a substance or its specific gravity is the number which expresses the ratio of its weight to the weight of an equal volume of water. Thus a piece of platinum weighs 21·5 times as much as an equal volume of water, while a piece of gold is 19·3 times as heavy. Hence it follows, that since a cubic cm. of water weighs 1 gram., a cubic cm. of platinum weighs 21·5 grams., and of gold 19·3 grams. In other words, the density of a substance is the same as the number of grams. that a cubic centimetre of it weighs.

EXPERIMENT **16.**—*Find the internal diameter of the glass tube given you—*

(1.) *By direct measurement.*
(2.) *By weighing the water contained in a given length of it.*
(3.) *By weighing the mercury contained in a given length of it.*

Instructions.—The density of mercury is 13·6. The tube can be closed at one end by a cork.

EXPERIMENT 17.—*Find the density of the metal cylinders given you, by weighing and measuring them.*

ELASTICITY.

EXPERIMENT 18.—*Find whether india-rubber is perfectly elastic as regards stretching.*

Instructions.—A substance is said to be perfectly elastic when it recovers its original form and dimensions *completely* after being distorted. Do not cut the india-rubber cord, but clamp it at any point required. Measure off a certain length, stretch it to a measured distance, and then remeasure it. Repeat this, stretching it more and more each time, and record your results in a tabular form.

EXPERIMENT 19.—*Observe the elongation produced by the same weight on different lengths of the same india-rubber cord.*

Instructions.—Clip the cord at any point required, and fix the stem of the clip in one of the holes provided in the wall. Tie a piece of string to the lower end of the cord, and hang the pan of your balance on to it, to put the weights in. Just above the string stick a pin through the cord. This pin serves to mark the bottom end of the length measured.

N.B.—The length, when stretched by the weight of the empty pan, must be regarded as the original length. Record in a tabular form. State what your results prove.

EXPERIMENT 20.‡—*Find within what limits the elasticity of india-rubber is simple.*[1]

Instructions.—The elasticity of a substance is said to be "simple" when the distortion produced is proportional to the force required to produce it. Thus, in the case of stretching, if, on doubling the stretching weight, the elongation is doubled, and on trebling the weight the elongation is trebled, then we say that the elasticity is simple.

It is generally found, however, that when anything is stretched beyond a certain limit, the elongation does not increase in proportion to the weight. You are required to find this limit.

Take a portion of the thinnest cord, about 2 metres long, and apply stretching weights, increasing by say 50 grams. at a time, and notice the elongation in each case. As long as the ratio between the elongation and weight is constant, the elasticity is simple.

Record thus:—

Original length of cord = ... cm.

Stretching Weight.	Length when stretched.	Elongation.	$\frac{\text{Elongation}}{\text{Weight}}$.
......	......	......	......
......	......	......	......
......	......	......	......

∴ the elasticity is simple till the cord is elongated ...... of its original length.

---

[1] According to Winkler, india-rubber is simply elastic only so long as the elongation is infinitely small. He gives as a formula $l = \frac{N}{E}(L + l)$, where L = original length; l = elongation; N = stretching weight (per unit of section); and E is a constant.

The better boys should test this formula.

In practice, with the rough method used, the elasticity was found to be simple up to very appreciable elongations.

EXPERIMENT **21.**‡—*Prove that the elongation of cords of the same length, when stretched by the same weight, is inversely as the area of their cross section, so long as they are not stretched beyond the limit of simple elasticity.*

Instructions.—Use the same length of each cord, and take it as long as possible, that the elongation to be measured may be great. Use the greatest weight for which the elasticity of the thinnest cord was found to be simple.

First measure the diameter of each cord with callipers in several places, and take the mean of the measures. Remember that the area of a circular section of radius r is πr^2.

Record thus:—

Cord No. 1 Thickness.	Cord No. 2 Thickness.	Cord No. 3 Thickness.
......	......	......
......	......	......
......	......	......
Mean	Mean	Mean

Stretching weight used = ... grams.
Original length of each cord = ... cm.

No. of Cord.	Elongation.	Average Thickness.	Sectional Area.	Area × Elongation.
......	......	......	......	......
......	......	......	......	......
......	......	......	......	......

If it is true that the elongation is inversely proportional to the area, then the product area × elongation will be always the same; for if two quantities are so connected that the one diminishes exactly in proportion as the other increases, it is evident that their product will always be the same.

EXPERIMENT 22.‡—*Find the co-efficient of elasticity of stretching for india-rubber, within the limits of simple elasticity.*

The elasticity of a substance is its power to resist distortion, and is measured by the *difficulty* and not the ease with which it is distorted.

The "co-efficient of elasticity of stretching" is the number which expresses the resistance of the substance to stretching.

To compare the elasticity of stretching of different substances, it is convenient to compare the elongation that would be produced by a weight of 1 gramme on a rod or cord of each substance 1 cm. long and 1 sq. cm. in area. The elongation which would be thus produced, expressed in centimetres, is the measure of the *ease* with which the substance is stretched, and the inverse of this, or $\frac{1}{\text{elongation}}$, is the measure of the *difficulty* of stretching for the substance.

The observations of Experiment 21 tell us that a certain weight acting on a cord of certain length and area produces a certain elongation, from which it is quite easy, by a proportion sum, to find the elongation that would be produced by a weight of 1 gram. on a piece of cord 1 cm. long and 1 sq. cm. in area. The inverse of this is the "co-efficient of elasticity" required.

EXPERIMENT 23.—*Observe the times required for large and small oscillations of a weight hanging by a thin wire, under the influence of torsion.*

Instructions.—Use a weight of 1 or 2 kilograms; fasten the wire firmly to it, and suspend it from the wall by a

clip. When the weight is at rest, make a mark on the front. Now twist it half round, and let it go. The wire will twist back again to its position of rest, and beyond, and then back again, and so on. When, after being released, it has twisted to the other side and back again to the starting-point, it is said to have performed a *complete oscillation.*

Observe with a watch, or by the clock, the time of, say, 20 such complete oscillations.

Now repeat the process, but twisting the weight three or four times round to begin with, and then again five or six times round to begin with. The angle through which the weight is twisted to one side or the other is called the amplitude of the oscillation.

Record thus :—

	Amplitude at starting.	Time of 20 oscillations.
	......	......
	......	......
	......	......
	Mean,	

The result shows that the duration of the oscillations is the same whether the amplitude be great or small; and it is a general law, that when an elastic body, in coming to rest after being distorted, performs oscillations that are of the same duration, whether they be great or small, then the elasticity is simple.

Hence we have learned indirectly that the elasticity of torsion in a wire is simple, or that the force required to keep it twisted, when turned once round, is half that required to keep it twisted when turned twice round, and so on.

EXPERIMENT 24.—*Repeat the same experiment with a different length of the same wire, also with a wire of the same length and of the same metal, but of different thickness.*

Instructions.—Use the same weight, tied on in the same way in each case.

You are not required to find the law which connects the length and thickness with the time of oscillation, but only the general influence of length and thickness on the time of oscillation. Write in your book what you find out.

EXPERIMENT 25.—*Repeat the experiment with wires of the same length and thickness, but of different metals.*

Instructions.—After making the experiment, write a list of the metals you have used in order of elasticity.

EXPERIMENT 26.—*Surface tension of liquids. Let drops of water fall on to a smoked glass, and observe their spheroidal form.*

Instructions.—The surface of a liquid acts like a stretched membrane, which, in endeavouring to contract, exerts a pressure on the liquid within.

A syringe out of which water or any other liquid may be conveniently expelled, drop by drop, is easily made by fixing a short piece of caoutchouc tubing on to a narrow glass tube, and closing the other end of the caoutchouc tubing with a piece of glass rod. If the glass tube be fixed in a vertical position, and the drops expelled by a gradual compression of the air in the caoutchouc tube, at about the same rate, they will be found to be all of very nearly the same size, which will depend on the diameter of the tube from which they are dropped. Observe the mark made on the smoked glass when the drop has fallen from different measured heights, showing how much the drop has been flattened before springing back to its original form.

EXPERIMENT **27.**—*Observe that a pellet of shot will not easily escape through the surface of the water contained in a narrow glass tube.*

Observation.—The common form of minimum thermometer is based on this principle.

SIMPLE PENDULUM.

EXPERIMENT **28.**—*Observe that the oscillations of a simple pendulum are isochronous,* i.e. *of equal duration, so long as they are not very large, and that they do not depend on the weight of the bob.*

Definition.—A simple pendulum is one formed of a weightless thread attached to a bob of very small dimensions. The length of the pendulum is the distance from the point of suspension to the centre of gravity of the bob.

Instructions.—Make a pendulum by attaching a thread to a bit of lead or to a small weight, such as one of the metal cylinders, of which you know the position of the centre of gravity. Observe the time of, say 20 larger oscillations, and then of 20 very small ones. Repeat the experiment with a bob of different weight, keeping the length of the pendulum the same.

EXPERIMENT **29.**—*Prove the "Law of the simple Pendulum,"* i.e. *that the square of the time of oscillation is proportional to the length of the pendulum.*[1]

Instructions.—If one quantity is so connected with another as to be always proportional to it, then the one divided by the other will be a constant quantity.

For if the connection between two quantities, A and B, is such that for any value of A there is a corresponding

[1] This law is generally expressed by saying that "the square of the *time of oscillation varies with* the length of the pendulum."

value of B, and that if A becomes twice or three times as great, B will likewise become twice or three times as great, etc., then it is clear that the fraction $\frac{A}{B}\left(\text{or}\,\frac{B}{A}\right)$ will always retain the same value, since, as the numerator becomes greater or smaller, so does the denominator in the same proportion.

(Under such circumstances A is said to vary as B.)

Hence, if we wish to prove that the square of the time of oscillation varies with the length of the pendulum, we must observe the time corresponding to different lengths, and then show that the fraction $\frac{\text{length}}{\text{time}^2}$ always keeps the same value.

The observations should be recorded thus:—

Length (L).	Time of an Oscillation (T).	$\frac{L}{T^2}$
......	......	......
......	......	......
......	......	......
......	......	......

and the numbers in the last column should be constant.

In measuring the length, it will be found convenient to tie a knot in the thread a few centimetres from the bob, so that the distance from the centre of gravity of the bob to the knot can be measured once for all, and added in each case to the distance from the knot to the point of suspension.

The time of one oscillation must always be found from the time of several (say ten or twenty).

So that the table just given must be filled in from one like the following, which must be made first:—

Distance of centre of gravity of bob from knot in thread = ... cm.

Length of thread from knot to Point of suspension.	Time of (say) 20 oscillations.
......	......
......	......
......	......
......	......

HYDROSTATICS.

EXPERIMENT 30.—*Fit up a short specific gravity pan by looping up the chains on one side of the balance, as in the figure, making the hook of wire.*

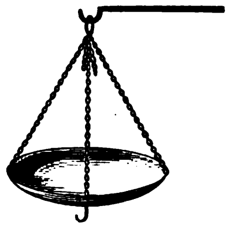


FIG. 5.

EXPERIMENT 31.—*Verify the Principle of Archimedes, viz., that when a solid is suspended in a liquid, the apparent loss of weight due to its being buoyed up by the liquid is equal to the weight of liquid displaced.*

Instructions.—The cylinder given you exactly fits the case. Hang the cylinder by a fine thread (horse-hair) from the hook of the short pan, placing the case in the pan above, and counterpoise. Then bring a beaker of water under the hanging cylinder, and raise it (on blocks if necessary) till the cylinder is immersed. On filling the case with water, equilibrium will be restored.

EXPERIMENT 32.—*Find the density of the metal cylinders given you, by weighing them first in air and then in water.*

Record thus :—

Brass cylinder. Weight in air = ... grams.
Weight in water = ... „

∴ weight of water displaced = ______

$$\therefore \text{density of brass} = \frac{\text{weight of metal in air}}{\text{wt. of equal vol. of water}} = \ldots\ldots$$

Verify your results by measuring the cylinders and

calculating the volume, and hence, knowing the weight, the density; remember that the density is the same as the weight in grams. of 1 C. cm.

EXPERIMENT 33.‡—*Find the density of a penny; and hence, being given the densities of copper and tin, calculate the proportion of each in the alloy.*

Instructions.—A more exact result is obtained by weighing eight or ten pennies together, first in air and then in water. Care must be taken, when weighing in water, not to entrap any air between them, which would buoy them up, and make the loss of weight in water appear too great, and therefore the density too small.

EXPERIMENT 34.—*Find the density of the boxwood ball given you, by weighing and measuring.*

Instructions.—The volume of a sphere of radius r is $\frac{4}{3}\pi r^3$.

EXPERIMENT 35.—*Find the density of the same ball by weighing in air and in water.*

Instructions.—The weight of the ball in air is known from Experiment 34.

To find the loss of weight in water, attach it to a sinker of lead. Then immerse ball and sinker in water, suspending them from the short pan, and counterpoise. Now remove the ball (after drying it) to the short pan, leaving the sinker in the water. Restore equilibrium with known weights. The weights added are the measure of the force with which the ball was thrust upwards by the water, *i.e.* of the weight of water displaced.

EXPERIMENT 36.—*Find the average thickness of the wire given you.*

Instructions.—The loss of weight in water gives the weight of water displaced, and thus the volume of the wire. But the volume = area of cross section × length.

$$= \pi r^2 \times l,$$

and since $\pi r^2 l = \text{volume}$

$$r^2 = \frac{\text{vol.}}{\pi l}$$

$$r = \sqrt{\frac{\text{vol.}}{\pi l}}$$

where r is the average radius.

EXPERIMENT 37.—*Find the density of turpentine, alcohol, and naphtha by comparing the heights of balancing columns in a* U *tube.*

Instructions.—The U tube should be made of a glass tube about 8 or 10 mm. in internal diameter. The arms should be about 30 cm. long, and as near together as possible. The tube can be clamped vertically against the metre measure, which thus serves as a scale. It is best to pour the heavier liquid in first. The other should be poured gently on to this through a funnel.

Record as follows, with a diagram:—

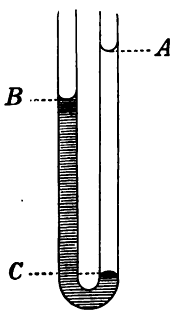


FIG. 6.

Scale reading for A ......
" " C ......
$\therefore AC =$ ______ = height of liquid.

Scale reading for B ......
" " C ......
$\therefore BC =$ ______ = height of balancing column of water.

$\therefore$ density of liquid $= \dfrac{BC}{AC} =$ ......

EXPERIMENT 38.—*Find the densities of the same liquids by weighing in the liquid.*

Instructions.—Suspend from the short pan an object which will sink both in the liquid and in water, and is not acted on by either, *e.g.* a piece of glass or a metal cylinder, and counterpoise. Then observe—

(1.) The loss of weight in water.
(2.) „ „ the liquid.

The loss of weight in water gives the weight of an equal bulk of water.

The loss of weight in the liquid gives the weight of an equal bulk of liquid.

N.B.—The greater the volume of the solid, the greater the accuracy of the result.

EXPERIMENT 39.—*Find the densities of the same liquids by means of the hydrometer.*

EXPERIMENT 40.—*Find the density of boxwood by floating a cube of it in water.*

Instructions.—Lower the cube gently into the water, keeping one face parallel to the surface, till it floats, part in and part out of the water. Since it now neither sinks nor rises, the force with which it is pushed up exactly balances its weight, that is to say, the weight of water displaced is equal to the weight of the cube.

But the volume of the cube is the area of its base multiplied by its height, and the volume of the water displaced is the area of the base multiplied by the height to which the cube is wetted.

That is to say, a mass of wood represented by the height of the cube has the same weight as a mass of water represented by the height of the wetted part.

$$\therefore \frac{\text{density of the wood}}{\text{density of the water}} = \frac{\text{height of wetted part}}{\text{whole height of cube}}.$$

Measure, therefore, the height of the cube and the height of the wetted part. If the latter is not the same at each edge, take the mean of the heights at the four edges.

EXPERIMENT 41.—*Find the density of boxwood by floating a right triangular prism of it in water.*

Instructions.—As before, the prism floats, part in and part out of the water, the weight of the water displaced being equal to the weight of the whole prism.

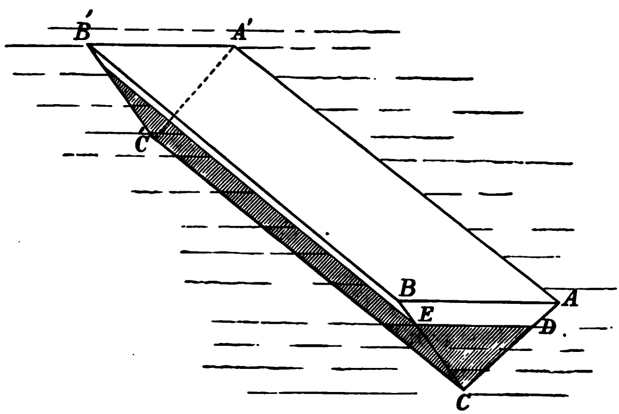


FIG. 7.

It is necessary to find the *volume* of the water displaced, and to compare that with the volume of the whole prism.

Let the prism float as in the figure. The edges AC and BC may with advantage be graduated, as also the corresponding edges $A'C'$ and $B'C'$ at the other end. Then the volume of the whole prism = altitude × area ABC, and the vol. in water (and therefore the vol. of an equal weight of water) = altitude × area DEC.

That is to say, a volume of water equal to the altitude $\times$ area DEC has the same weight as a piece of wood whose volume is altitude $\times$ area ABC, and, clearly, the density of the wood is to the density of the water as vol. of water to vol. of wood;

$$\text{or density of prism} = \frac{\text{altitude} \times \text{area } DEC}{\text{altitude} \times \text{area } ABC} = \frac{\text{area } DEC}{\text{area } ABC}.$$

N.B.—It may happen, that owing to the density not being quite uniform throughout, the edges BB' and AA' are not quite horizontal and parallel to the surface of the water, and it is therefore best to observe not only the lengths CD and CE, but also $C'D'$ and $C'E'$, and to take the average of the values at each end of the prism.

EXPERIMENT 42.—*Find the density of the solid given you in small pieces* (e.g. *shot corns*) *by using a specific gravity bottle.*

Instructions.—After finding the weight of the solid in air, place it in a watch-glass in the same pan with a specific gravity bottle filled up to the mark, and counterpoise. Then pour the solid into the bottle, the liquid overflows, and must be mopped up with blotting-paper till it is again at the mark. Now observe the weight necessary to restore $=^{m}$; this gives the weight of water displaced.

EXPERIMENT 43.—*Find the density of sodium.*

Instructions.—This cannot be weighed in air, as it oxidises so rapidly; nor in water, which it decomposes. It must therefore be placed in a vessel of some such liquid as naphtha, which it does not attack, and the whole counterpoised, and the loss of weight observed which is caused by removing the sodium. This gives the weight in air.

The weight of naphtha displaced is found by using a specific gravity bottle, filled with that liquid instead of with water, exactly as in the preceding experiment, and knowing the density of naphtha we know the weight of an equal vol. of water.

EXPERIMENT 44.—*Make a barometer, repeating Torricelli's experiment.*

Instructions.—Fill the barometer tube with mercury, cautiously, by means of a funnel, till within about 2 cm. from the top; then close the end with the finger, and invert the tube twice or thrice, so as to let a large bubble of air travel up and down the tube and take up the smaller bubbles. When these are got rid of, fill up to the top, close the end with the finger, and invert the tube in a small mortar of mercury standing in a tray, remove the finger, and the mercury in the tube will descend to a certain height above the level of that outside. Measure this height.

If there is no air above the mercury in the tube, the liquid will strike the end of the tube with a metallic click, when the tube is closed by the finger below, and shaken gently up and down. Make the experiment.

EXPERIMENT 45.—*Verify Boyle's law for pressures greater than that of the atmosphere.*

Instructions.—The law is that the volume of a quantity of imprisoned air decreases exactly in proportion as the pressure on it is increased. This is to be proved by entrapping some air in the short leg of the manometer, observing its volume and the pressure upon it, and then increasing the pressure by pouring mercury into the long leg and observing the reduced volume. If, as the pressure (P) increases the volume (V) diminishes, then the product $P \times V$ will retain the same value throughout; and *conversely, if* the product PV retains the same value

throughout, it proves that the volume diminishes as the pressure increases.

First, observe the atmospheric pressure at the time of your experiment, either by reference to the laboratory barometer, or by repeating Experiment 44. Call this pressure H mm.

Place your meter measure by the side of or behind the manometer to serve as a scale; then, using a funnel, pour at first just sufficient mercury into the tube to close the bend. Read and record the height of the mercury in each tube. Pour in more mercury, read and record again, and so on. The mercury that is poured in will probably carry down many air bubbles with it, which must be got rid of by agitating the tube, great care being taken not to let any of the air imprisoned in the short leg escape. The process of pouring in mercury, and observing, on each occasion, the height at which it stands in each branch, should be repeated at least four times, till the long tube is quite full. Record with a diagram as follows:—

Reading for $C =$ ......
" " $B_1 =$ ......
$\therefore$ vol. of air $= V_1 = C - B_1 =$ ______

Reading for $A_1 =$ ......
" " $B_1 =$ ......
$\therefore$ Press. $= P_1 = A_1 - B_1 + H =$ ______
$\therefore V_1 P_1 =$ ......

Reading for $C =$ ......
" " $B_2 =$ ......
$\therefore V_2 =$ ______

Reading for $A_2 =$ ......
" " $B_2 =$ ......
$\therefore P_2 = A_2 - B_2 + H =$ ______
$\therefore V_2 P_2 =$ ......

and similarly for $V_3 P_3$ and $V_4 P_4$.

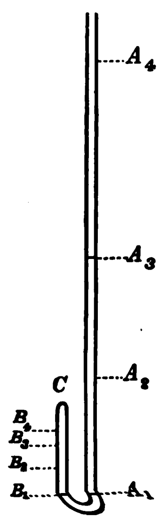


Fig. 8.

Then arrange the results thus :—

$$
\begin{array}{ll}
V_1 P_1 = & \ldots\ldots \\
V_2 P_2 = & \ldots\ldots \\
V_3 P_3 = & \ldots\ldots \\
V_3 P_4 = & \ldots\ldots \\
\hline
\text{Mean} & \\
\hline
\end{array}
$$

$\therefore$ maximum error$=\ldots\ldots=\ldots$per cent.

EXPERIMENT 46.—*Verify Boyle's law for pressures less than that of the atmosphere.*

Instructions.—First repeat Torricelli's experiment, so as to find the pressure of the atmosphere H.

Then repeat the experiment with the tube not quite full of mercury, leaving say one decimeter of air (which is of course at the pressure of the atmosphere H) between the top of the mercury and the finger before inverting the tube.

When the finger is removed after inversion, this air will expand, and the pressure upon it will be equal to the atmospheric pressure minus that of the column of mercury in the tube, which the atmospheric pressure has to balance in addition to the pressure of the imprisoned air. The height of this column must therefore be measured as well as the volume to which the imprisoned air has expanded on removing the finger.

The fact that the closed end of the tube is rounded will be a source of error unless we estimate the value of the rounded part. This must be done by pouring a little mercury into the empty tube, and marking its level A, and weighing it in a watch glass (call the weight W_1). Then pour in a centimetre or two more, and note the level B, and weigh again (call the weight W_2). Let the length of A to B be n centimetres.

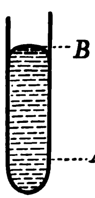


FIG. 9.

Then the weight of n centimetres of mercury is $W_2 - W_1$,

$\therefore$ the weight in 1 cm. of straight tube is $\frac{W_2 - W_1}{n}$;

and $\therefore$ the length of tube from A to the end is equivalent to $\frac{W_1}{\frac{W_2 - W}{n}}$ centimetres of straight tube.

Let us call this number C.

The observations should be recorded as follows:—

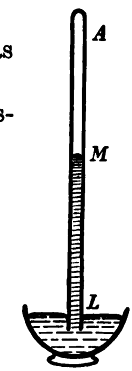


FIG. 10.

Vol. of imprisoned air at atmospheric pressure $(= V_1) = \ldots\ldots$

Atmospheric pressure $(= P_1) = \ldots\ldots$

$\therefore V_1 P_1 =$

Height $MA = \ldots$cm.

$\therefore$ new vol. of air$= MA + C = \ldots$cm. $(= V_2)$.

Height $LM = \ldots$cm.;

$\therefore$ new pres. of air$= P_1 - LM = \ldots$cm. $(= P_2)$;

$\therefore V_2 P = \ldots\ldots$

The experiment should be repeated with increasing volumes of imprisoned air.

HEAT.

EXPERIMENT 47.—*Verify the freezing point and boiling point of the thermometer given you.*

Instructions.—Surround the thermometer with melting ice to verify the freezing point, and to verify the boiling point pass it through the cork of a flask containing water till the bulb just touches the surface. Boil the water, letting the steam escape through a second opening in the cork filled with a glass tube bent to an angle of 120°.

Experiments on the Unit of Heat.

Definition.—The unit quantity of heat is the amount required to raise a given weight of water through a given range of temperature.

In what follows the unit will be taken as the quantity of heat required to raise 1 gram. of water 1° C.

Note.—If a gram. of water *loses* a unit of heat, it will fall 1° C. in temperature.

EXPERIMENT 48.—*To prove that, so far as we can observe with the apparatus at our disposal, the unit of heat is constant, whatever the temperature of the water,* i.e. *that the same amount of heat is required to raise* 1 *gram. of water from* 3° *to* 4° *as from* 23° *to* 24°, *or from* 33° *to* 34°, *etc.*

Instructions.—Heat some water in a beaker to a temperature of, say, 40°. Take, in another beaker, an equal quantity of cooler water at the temperature of the air, say 10°; mix the two together. If the resulting temperature of the mixture is 25°, *i.e.* midway between 10° and 40°, it proves that the heat which the hot water lost in falling from 40° to 25° (*i.e.* through 15°) is exactly sufficient to raise the cooler water through the same number of degrees —*i.e.* the "unit" has the same value between 10° and 25° as between 25° and 40°.

EXPERIMENT 49.—*Vary the above experiment by taking a weight of water W at a temperature T, and a different weight W' at a lower temperature t.*

Instructions.—Then, if θ be the resulting temperature of the mixture which must be observed, we should find

Heat lost by hot water = Heat gained by cold water

$$W\,(T-\theta) = W'\,(\theta - t)$$

Verify this equation by your experiment.

Note.—In both of these last experiments some heat is lost to the air while the mixture is being stirred, and before the temperature can be observed. If the liquid be very hot, this loss will be rapid, and it must be measured and taken into account, which may be done by observing the rate at which the mixture continues to cool, from which the loss between the time of mixture and the time of observation can be estimated.

EXPERIMENT 50.—*Repeat the last experiment, observing with a watch (a) the time of mixture; (b) the time of taking the temperature of the mixture; (c) the time at which the mixture has cooled down 1° more; (d) the time at which it has cooled 2° more; and so on, say till it has cooled 4° below the temperature θ first observed.*

Instructions.—Record as in the following example:—

Before Mixture.

Temperature of Hot Water (T).	At Time of Mixture. H.	M.	S.
61°	0	12	4

After Mixture.

Temperature of Mixture (θ).	At Time of Mixture. H.	M.	S.	Difference.
23°	0	12	22	
				12″
22°	0	12	34	
				12″
21°	0	12	46	
				13″
20°	0	12	59	

The third column of differences gives the time taken in cooling through each degree. Here we see that at first the rate was 1° in 12″, and we may estimate that this was the rate during the 18″ required for mixing, in which time the loss would therefore be $\frac{18^\circ}{12}=1^\circ{\cdot}5$.

$\therefore$ the true temperature of the mixture must be taken as $\theta+1^\circ{\cdot}5=23^\circ+1^\circ{\cdot}5=24^\circ{\cdot}5$.

Note.—It is evident also that there is a further source of inexactness in Experiments 48 and 49, viz., that some of the heat of the hot water is given to the vessel into which it is poured, as well as to the cold water in that vessel. It is not difficult to measure this amount, and we shall find it to be comparatively small.

EXPERIMENT 51.—*Heat some water to a temperature T° (say 50°), and pour it into the* EMPTY *vessel which has been used, and which is at the temperature t° of the air. Observe the resulting temperature θ and the rate of cooling, for which correction must be made, as in the previous example. Weigh the water added.*

Instructions.—Let its weight be W grammes. Then the heat lost to the vessel is $W(T-\theta)$ units, and this has raised the vessel through $(\theta-t)^\circ$. $\therefore$ to raise the vessel through 1° we shall need $\frac{W(T-\theta)}{\theta-t}$ units of heat. This number is called the *specific capacity* of the vessel. If it were made of a well-conducting substance, such as copper or tin, so as to be of the same temperature throughout, then, by dividing this number by the weight in grams. of *the vessel,* we get the number of units of heat required to

raise 1 gram. of the substance through 1° C., *i.e.* the *specific heat* of the substance of which the vessel is made.

Note.—If the thermometer with which the temperature of the mixture is observed is at the temperature of the cooler water to begin with, it too will take up some of the heat of the hot water. Its specific capacity should therefore be found as follows:—

EXPERIMENT 52.—*To find the specific capacity of the thermometer.*

Instructions.—Into the vessel whose specific capacity has been found pour just sufficient water to cover the bulb of the thermometer. Let the weight of this water be W grams. and its temperature be $t°$. Now heat the thermometer to about 100°; dry it, and hold it just above the surface of the water; of course it will cool rapidly. Notice the temperature (T), and plunge it in, and notice the final temperature θ of the mixture. The thermometer, in falling through $(T-\theta)°$, raises the water and the vessel through $(\theta-t)°$, *i.e.* it gives up $(\theta-t)$ units to each gram. of water and $(\theta-t)\times$ specific capacity of vessel to the vessel. $\therefore$ calling this specific capacity K, we see that a loss of $W\times(\theta-t)+(\theta-t)\,K$, or $(\theta-t)\,(W\times K)$ units, lowers the temperature of the thermometer $(T-\theta)°$. $\therefore$ the specific capacity of the thermometer, or the quantity of heat required to raise it 1°, is

$$\frac{(\theta-t)\,(W+K)}{(T-\theta)} \text{ units.}$$

EXPERIMENT 53.—*To find the specific heat of a metal by the method of mixtures.*[1]

Instructions.—Having found the specific capacity (K) of the calorimeter and (Z) of the thermometer, place a known weight of water (W') in the calorimeter, and a known weight of the metal (W) cut into small pieces in a wide test-tube, in which it can be raised to 100°, by holding it in boiling water. Pour the metal rapidly into the cold water at temperature t, and observe the resulting temperature θ of the mixture, which must be corrected for cooling.

Let x be the specific heat of the metal (*i.e.* the number of units of heat required to alter the temperature of 1 gram. of it 1° C.).

Then

Heat lost by metal=heat gained by water+heat gained by calorimeter+heat gained by thermometer;

$$\text{or } W(100-\theta)x = W'(\theta-t)+K(\theta-t)+Z(\theta-t)$$
$$=(\theta-t)(W'+K+Z);$$
$$\therefore x=\frac{(\theta-t)(W'+K+Z)}{W(100-\theta)}.$$

The whole may be recorded as in the following example:—

[1] A clear conception of specific heat is so important, that any boy who seems likely to be at all confused by the introduction of the corrections of the preceding experiments should be set to find a specific heat without them.

To find the Specific Heat of Lead.

	Gr.
Weight of lead (W), ...	46·7
" water (W'), ...	24·3
Temperature of water before mixture, . .	16°
" lead " . .	100°

	H. M. S.
Time of mixture, ...	0 44 30
Temperature of mixture 19°·8 at time, .	0 44 50
" " 18°·8 " .	0 46 30
" " 17°·8 " .	0 48 10
∴ rate of cooling per sec., ...	·01°
∴ loss during the 20″ required for mixing, .	·2°
∴ true value of temperature of mixture (θ), .	20°
Spec. cap. of calorimeter as previously determd. (K)	7·2
" thermometer (Z), ...	·3

$$\therefore \text{spec. heat} = \frac{(\theta - t)(W' + K + Z)}{W(100 - \theta)}$$

$$= \frac{4(24{\cdot}3 + 7{\cdot}2 + {\cdot}3)}{46{\cdot}7(100 - 20)}$$

$$= {\cdot}034.$$

N.B.—The smaller the quantity of water taken the greater the rise in temperature to be measured, and the more accurate the result; but there must always be enough to cover the bulb of the thermometer.

EXPERIMENT 54.—*To find the latent heat of water.*

Definition.—The latent heat of water is the number of units of heat required to turn the unit weight of ice at zero into water at zero.

Instructions.—Into a calorimeter of known specific capacity (K) place a known weight (W') of water at a known temperature (T) (say 50° C.).

Into this put fragments of ice dried with blotting paper, and stir rapidly till all is melted. Observe the resulting temperature θ of the mixture.

By weighing the mixture, find out the weight W of ice added.

Let L be the latent heat of water.

Then heat lost by the water and calorimeter in falling from $T°$ to $\theta°$=heat required first to turn W grams. of ice into water at 0°, and then to raise these W grams. of water from 0° to $\theta°$;

$$\therefore (K+W')(T-\theta)=WL+W\theta;$$

$$\therefore L=\frac{(K+W')(T-\theta)-W\theta}{W}.$$

N.B.—If the water be hotter than the air before mixture, and cooler afterwards, it will first lose heat from the air and afterwards gain it; and it is perhaps best so to adjust the quantities of ice and water, that the temperature of the mixture is finally as much below that of the surrounding air as the temperature of the hot water was above it.

EXPERIMENT 55.—*To find the Latent Heat of Steam.*

Definition.—The latent heat of steam is the number of units of heat required to convert the unit weight of water *at 100° C. into* steam at 100° C., *or* conversely, it is the

amount of heat given up by the unit weight of steam at 100° C. on being condensed into water at 100° C.

Into a known weight of water W' in a flask, lead the steam from another flask in which water is kept briskly boiling, through a tube which should be as short as possible to prevent condensation on the way. The bottom end of the tube should be fitted as in fig. 11, with a narrow tube A inside a wider tube B, the space between serving to catch steam that is already condensed.

The temperature of the water and air (t) before the experiment must be noticed, as well as the time of the beginning and end of the experiment, and the final temperature θ of the mixture; and the rate of cooling at the end of the experiment must be found in the usual way.

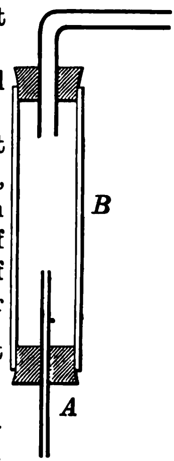


FIG. 11.

The weight W of steam that has entered is found by weighing.

If the rate of cooling be found to be at the end of the experiment $n°$ per second, then since the rate was *nothing* to begin with (the water being at the temperature of the air), we may take the *average* rate of cooling to be midway between 0° and $n°$ per second, *i.e.* $\frac{n°}{2}$, and this correction must be applied to θ.

The latent heat of steam is found by equating the heat lost by the steam, first in condensing, and then in falling from 100° to $\theta°$, to the heat gained by the water in rising from $t°$ to θ.

Thus

$$W\{L+(100-\theta)\}=W'(\theta-t);$$

$$\therefore L=\frac{W'(\theta-t)-W(100-\theta)}{W}$$

where L is the latent heat.

The whole may be recorded in the following form:—

Latent Heat of Steam.

Weight of cold water (W'), ...	......
Temperature „ (t), ...	......
Time of beginning experiment, ...	......
Time of ending „	......
∴ duration of experiment, ...	......
Temperature at end (θ), ...	......
Time when the temperature was $\theta^\circ - 1^\circ$, . .	......
„ „ „ „ $\theta^\circ - 2^\circ$, . .	......
„ „ „ „ $\theta^\circ - 3^\circ$, . .	......
∴ rate of cooling per sec. at end of experiment, .	......
∴ loss of temperature due to average rate of cooling, ...	......
∴ corrected value of θ, ...	......
Weight of water + steam, ...	......
∴ weight of steam added (W), ...	......
$\therefore L = \dfrac{W'(\theta - t) - W(100 - \theta)}{W} =$.	......

N.B.—If the quantity of water taken be large, the heat lost to the flask and thermometer is relatively insignificant.

It is instructive to make the experiment once with a single, simple tube to introduce the steam without catching what has been condensed in the passage, and to notice *the alteration* in the value obtained for L.

EXPERIMENT 56.‡—*To find roughly the co-efficient of expansion of air.*

Instructions.—1st Method—Constant volume.—A thin glass tube of about 10 mm. internal diameter and about 45 cm. long, is closed at one end, and then bent into the form of a manometer, the closed branch being about 15 cm. long.

Some air is imprisoned by pouring in enough mercury to close the bend, and the difference of level of the mercury in the two tubes noted; this + the height of the barometer at the time gives the pressure of the imprisoned air at temperature t. About 150 mm. of mercury is then poured into the long leg, and the apparatus is then plunged into a deep vessel of water, which is heated until the compressed air regains its original volume, when the difference of level in the two branches of the manometer is observed. This + the atmospheric pressure H gives the pressure at temperature T.

The temperature of the water which is being heated must be kept uniform throughout by stirring.

Let x be the unknown co-efficient of expansion of air for 1° C. Then the volume imprisoned at temperature t would, if allowed to expand, on being heated to $T°$ at the same pressure, increase in the ratio $\frac{1+xT}{1+xt}$; ∴ the increase of pressure necessary to keep the volume the same must be in the same proportion.

$$\therefore \frac{1+xT}{1+xt} = \frac{\text{Final Press.}}{\text{Initial Press.}},$$

from which equation we may easily find x.

N.B.—Here we have taken into account neither the expansion of the glass vessel containing the air nor that of the mercury.

EXPERIMENT 57.‡—*To find roughly the co-efficient of expansion of air.*

Instructions.—2nd Method—Constant Pressure.—The volume of a specific gravity flask, fitted with a long bent neck as a weight thermometer, is first found by weighing the water it will contain. Let this weight be called W.

Now plunge the empty flask in water at a temperature T (about 60°). The air inside expands and escapes, and the mouth of the neck is to be dipped into water so that as the air cools the water may be driven into the flask. When the flask has cooled down to the temperature of the air (t), the weight of water that has thus entered is to be found; call this weight w.

Let x be the co-efficient of expansion of air.

Then the volume W that was in the flask at temperature t expands, on heating to $T°$, to the volume $W\dfrac{1+xT}{1+xt}$.

But the flask will only hold a volume W;

$$\therefore\ W\frac{1+xT}{1+xt}-W=W\left(\frac{1+xT}{1+xt}-1\right)\text{ escapes }=W\frac{x(T-t)}{1+xt};$$

$\therefore$ the fraction of the whole volume at this temperature which escapes is $\dfrac{W\dfrac{x(T+t)}{1+xt}}{W\dfrac{1+xT}{1+xt}}=\dfrac{x(T+t)}{1+xT}$, but the fraction of the whole that escapes is $\dfrac{w}{W}$; $\therefore\ \dfrac{x(T+t)}{1+xT}=\dfrac{w}{W}$, from which x is easily found.

EXPERIMENT 58.‡—*To find the co-efficient of apparent expansion of mercury in glass by means of the weight thermometer.*

Instructions.—Counterpoise the weight thermometer; then fill it with mercury and restore equilibrium with known weights (W), observing at the same time the temperature (t) of the air, and therefore of the mercury in contact with it. Suspend the thermometer in a net or handkerchief in a large beaker full of water, so that the mouth projects beyond the side. Now heat the water to a temperature T (say 80°), catching the mercury that is expelled in a watch glass. Weigh this expelled mercury, and call its weight w. Then, disregarding the expansion of the glass vessel, we see that the weight $W-w$ that is left in the vessel at $t°$ would, if again heated to $T°$, exactly fill the space taken up by a weight W at $t°$, and since at any given temperature the weights are proportional to the volumes, therefore a volume $W-w$ at $t°$ will, when heated to $T°$, become $W-$, *i.e.* will increase by a volume w; therefore one volume when heated through one degree will increase by the amount $\frac{w}{W-w} \times \frac{1}{T-t}$, which is therefore the co-efficient of apparent expansion of mercury in a vessel made of a particular kind of glass.

Educational Works

First Latin Writer. By G. L. BENNETT. Cr. 8vo. 3*s*. 6*d*.

First Latin Exercises. Being the Exercises with Syntax Rules and Vocabularies from the above work. Cr. 8vo. 2*s*. 6*d*.

Latin Accidence. From a "First Latin Writer." Cr. 8vo. 1*s*. 6*d*.

Second Latin Writer. By G. L. BENNETT. Cr. 8vo. 3*s*. 6*d*.

Easy Latin Stories for Beginners. By G. L. BENNETT. Cr. 8vo. 2*s*. 6*d*.

Selections from Cæsar. Edited by G. L. BENNETT. Sm. 8vo. 2*s*.

Arnold's Henry's First Latin Book. By C. G. GEPP. 12mo. 3*s*. [The original Edition is still on sale.]

The Æneid of Vergil. Edited by F. STORR. Cr. 8vo.
Books I. and II. 2*s*. 6*d*.
Books XI. and XII. 2*s*. 6*d*

Virgil Georgics. Book IV. Edited by C. G. GEPP. Sm. 8vo. 1*s*. 6*d*.

Cicero de Amicitiâ. Edited by A. SIDGWICK. Sm. 8vo. 2*s*.

Cæsar de Bello Gallico. Books I-III. Edited by J. MERRYWEATHER and C. TANCOCK. Sm. 8vo. 3*s*. 6*d*. Book I. separately, 2*s*.

The Beginner's Latin Exercise Book. By C. J. S. DAWE. Cr. 8vo.

First Steps in Latin. By F. RITCHIE. Cr. 8vo.

Gradatim. An Easy Latin Translation Book. By H. HEATLEY and H. KINGDON. Sm. 8vo.

A Primer of Greek Grammar. By E. ABBOTT and E. D. MANSFIELD. Cr. 8vo. 3*s*. 6*d*., or separately.

Accidence. 2*s*. 6*d*.

Syntax. 1*s*. 6*d*.

A Practical Greek Method for Beginners. THE SIMPLE SENTENCE. By F. RITCHIE and E. H. MOORE. Cr. 8vo. 3*s*. 6*d*.

Stories in Attic Greek. By F. D. MORICE. Cr. 8vo. 3*s*. 6*d*.

A First Greek Writer. By A. SIDGWICK. Cr. 8vo. 3*s*. 6*d*.

An Introduction to Greek Prose Composition. By A. SIDGWICK. Cr. 8vo. 5*s*.

Scenes from Greek Plays. Rugby Edition. By A. SIDGWICK. Sm. 8vo. 1*s*. 6*d*. *each*.

ARISTOPHANES:—THE CLOUDS—THE FROGS—THE KNIGHTS—PLUTUS.

EURIPIDES:—IPHIGENIA IN TAURIS—THE CYCLOPS—ION—ELECTRA—ALCESTIS—BACCHÆ—HECUBA.

Homer's Iliad. Edited by A. SIDGWICK. Sm. 8vo.
Books I. and II. 2*s*. 6*d*.
Book XXI. 1*s*. 6*d*.
Book XXII. 1*s*. 6*d*.

The Anabasis of Xenophon. Edited by R. W. TAYLOR. Cr. 8vo.
Books I. and II. 3*s*. 6*d*.
Or separately, Book I., 2*s*. 6*d*.; Book II., 2*s*.
Books III. and IV. 3*s*. 6*d*.

Xenophon's Agesilaus. Edited by R. W. TAYLOR. Cr. 8vo. 2*s*. 6*d*.

Stories from Ovid in Elegiac Verse. By R. W. TAYLOR. Cr. 8vo. 3*s*. 6*d*.